

METHOD FOR ELIMINATION OF PARASITIC BIPOLAR ACTION IN
SILICON ON INSULATOR (SOI) DYNAMIC LOGIC CIRCUITS

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BACKGROUND OF THE INVENTION

Cross Reference to Related Application

This is a divisional application of U.S. Patent
Application Serial No. 09/240,244, filed January 29, 1999,
10 entitled "METHOD AND APPARATUS FOR ELIMINATION OF PARASITIC
BIPOLAR ACTION IN COMPLEMENTARY OXIDE SEMICONDUCTOR (CMOS)
SILICON ON INSULATOR (SOI) CIRCUITS", which is herein
incorporated by reference.

15 A. Field of the Invention

The invention relates generally to a method and
apparatus for reducing the effects of parasitic bipolar
discharge of silicon-on-insulator (SOI) electronic devices.
20 More specifically, the invention relates to eliminating the
unwanted effect of parasitic bipolar discharge of SOI field
effect transistors (FET) in dynamic logic circuits.

B. Description of Related Art

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Silicon-on-insulator (SOI) technology is an enhanced

silicon technology currently being utilized to increase the performance of digital logic circuits. Utilizing SOI technology designers can increase the speed of digital logic integrated circuits while reducing their overall power consumption. These advances in technology will lead to the development of more complex and faster computer integrated circuits that operate with less power.

In recent years Metal Oxide Semiconductor (MOS) Field Effect Transistor (FET) integrated circuits and Complementary Metal Oxide Semiconductor (CMOS) FETs have gained popularity and are the most widely used type of integrated circuit technology. Today, CMOS electronic devices provide advantages of higher operating speeds, smaller size, lower power consumption, and are increasingly becoming cheaper to manufacture as a result of smaller component size, higher manufacturing production yields per semiconductor wafer, and larger wafer sizes. The most popular integrated circuit devices manufactured utilizing CMOS technology are microprocessors, memory, and digital logic circuits.

Traditional MOS and CMOS semiconductors consist of a metal on an oxide layer that is placed on a silicon substrate. The added impurities in the silicon substrate enable these devices to operate as transistors. On the other hand, SOI semiconductors include a thin layer of silicon placed on top of an insulator, such as silicon oxide

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or glass, and a MOS transistor built on top of this structure. The main advantage of constructing the MOS transistor on top of an insulator layer is to reduce the internal capacitance of the transistor. This is
5 accomplished by placing the insulator oxide layer between the silicon substrate and the impurities required for the device to operate as a transistor. Reducing the internal capacitance of the transistor increases its operating speed. Therefore, with SOI technology faster MOS transistors can be
10 manufactured resulting in higher performance semiconductors to fuel emerging needs for faster electronic devices.

SOI technology has several drawbacks. An inherent drawback of placing a MOS transistor on top of a SOI layer is that the MOS transistor is actually placed in parallel
15 with a bipolar junction transistor. If enough current is passed through the MOS transistor, the parasitic bipolar transistor will turn on. This causes an unwanted effect called bipolar discharge and lowers the performance of the MOS transistor.

20 High speed CMOS circuits often employ a domino circuit technique that utilizes pre-charging to improve the gate speeds of the transistors. Dynamic circuit nodes are pre-charged during each clock cycle to a certain level. The problem with SOI FETs is that the parasitic bipolar
25 transistor causes bipolar discharge. This is undesirable because it causes an unintended loss of charge on the drain

nodes of the dynamic circuit.

Normally, parasitic bipolar action does not manifest itself in conventional, bulk, MOS transistors because the base of the bipolar transistor is always kept at ground potential, keeping the bipolar off. In SOI, the body of the MOS FET device, or base of the bipolar transistor, is floating and can be charged high by junction leakages induced when the drain and source terminals of the MOS FET are at a high potential. Subsequently, if the source is pulled to a low potential, the trapped charge in the base area is available as parasitic base current. The parasitic base current activates the bipolar transistor and generates a collector current at the drain terminal of the MOS FET. The unintentional loss of charge could lead to system failure, for example, by erroneously switching logic state.

As a result, it can be seen that there is a need to minimize the effect of parasitic bipolar transistors in parallel with MOS transistors in dynamic logic circuits.

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In accordance with a preferred embodiment, the present invention provides an apparatus and method to overcome the unwanted effects of parasitic bipolar discharge in silicon-on-insulator (SOI) field effect transistors (FET) by inserting a discharging device at intermediate nodes of the dynamic circuit to keep the voltages at the sources at a low potential. Furthermore, the discharging device is turned on prior to discharging the nodes of the SOI FET in domino logic circuits to disable the body charge of the SOI FET.

In another embodiment, the present invention provides, 25 a method of eliminating parasitic bipolar transistor action in a Silicon on Insulator (SOI) Metal Oxide Semiconductor

(MOS) device, the method comprising: controlling the conduction of an active discharging device, said active discharging device being coupled to said SOI device, whereby the parasitic bipolar transistor is deactivated.

5 In yet another embodiment, the present invention provides a Silicon on Insulator(SOI) dynamic logic circuit having an input, an output, and a clock, comprising: a plurality of stacked SOI Metal Oxide Semiconductor (MOS) transistors interconnected to perform a predetermined logic
10 function defining a common node and a plurality of intermediate nodes, said common node being coupled to a pre-charging device and said intermediate node having a corresponding input coupled to said stacked transistors; and a plurality of active discharging transistors interconnected
15 between said intermediate nodes and any one of said corresponding input to said stacked transistors.

In a further embodiment, the present invention provides a method of eliminating parasitic bipolar transistor action in a Silicon on Insulator (SOI) Metal Oxide Semiconductor
20 (MOS) dynamic logic circuit having an input an output, and a clock, comprising a plurality of stacked SOI Metal Oxide Semiconductor (MOS) transistors interconnected to perform a predetermined logic function defining a common node and a plurality of intermediate nodes, said common node being
25 coupled to a pre-charging device and said intermediate nodes having a corresponding input coupled to said stacked

transistors; and a plurality of active discharging
transistors interconnected between said intermediate nodes
and any one of said corresponding inputs to said stacked
transistors, the method comprising: controlling the
5 conduction of said active discharging transistors during a
pre-charge cycle; and actively discharging said intermediate
nodes of the SOI stacked transistors, whereby the parasitic
bipolar transistors are deactivated and the charge at said
common node is maintained at a predetermined level.

10 These and various other features and advantages of the
present invention will become readily apparent to those
skilled in the art from the following detailed description
and corresponding drawings. As will be realized, the
invention is capable of modification without departing from
15 the invention. Accordingly, the drawing and description are
to be regarded as being illustrative in nature, and not as
restrictive.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross sectional diagram of a silicon-on-insulator (SOI) field effect transistor (FET) and a parasitic bipolar transistor.

5 Figure 2 is an equivalent schematic diagram of the SOI field effect transistor FET and bipolar transistor.

Figure 3 is a dynamic logic circuit schematic diagram illustrating one embodiment of the present invention that eliminates the unwanted effects of the parasitic bipolar
10 transistor device in SOI FET dynamic circuits.

Figure 4 is a dynamic logic circuit schematic diagram illustrating one embodiment of the present invention that eliminates the unwanted effects of the parasitic bipolar transistor device in SOI FET dynamic circuits using NFET
15 pre-charging devices.

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DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

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The illustrated embodiment of the invention is principally directed to reducing or eliminating the unwanted effects of the parasitic bipolar transistor in silicon-on-insulator (SOI) field effect transistor (FET) dynamic logic circuits. The dynamic logic circuit may have an input, an output, a clock, and a plurality of stacked SOI Metal Oxide Semiconductor (MOS) FETs interconnected to perform logic functions defining a common node, said common node coupled to a pre-charging device, a plurality of intermediate nodes having a corresponding input coupled to said stacked transistors; and a plurality of active discharging transistors interconnected between said intermediate nodes and any one of said corresponding input to said stacked transistors. The discharging devices actively discharges the intermediate nodes of the stacked SOI FETs during the pre-charge phase of dynamic logic circuits, whereby the parasitic bipolar transistor is deactivated and the charge on the common node is maintained at a high potential level.

Figure 1 illustrates a cross sectional view of a silicon-on-insulator (SOI) negative field effect transistor (NFET) 10 and a parasitic bipolar transistor. The NFET 10 is built on a silicon dioxide, i.e. glass, insulating layer 12. In bulk (non SOI) the base region of the parasitic bipolar transistor is always maintained at ground potential.

Therefore, no base current is generated and no resulting collector current flows through the bipolar device.

However, in SOI transistors, the body of the FET device 14, or base region of the parasitic bipolar transistor, which lies beneath the gate 22 of the NFET, is floating. The body 14 of the transistor can become charged to a high potential by junction 16 leakage induced whenever both the drain 18 and source 20 terminals are at a high potential. In this illustration the drain 18 of the NFET is the n+ or collector region of the parasitic bipolar and the source 20 is the n+ or emitter region of the parasitic bipolar.

If the body 14 of the FET charges to a high potential and the source 20 is pulled to a low potential, the trapped charge in the body 14, or base region, becomes available as parasitic base current. If the parasitic base current is of sufficient magnitude it will activate the parasitic bipolar transistor and thus generate a collector current at the drain 18. The collector current, flowing in parallel with the drain 18 current, is undesirable as it causes a loss of charge at the drain 18 node of the dynamic circuit.

Figure 2 illustrates an equivalent schematic diagram 24 of the SOI field effect transistor NFET 26 and the parallel parasitic bipolar NPN transistor 28. NFET 26 also includes gate terminal 30. The drain 36 of NFET 26 is equivalent to the collector 38 of the parasitic bipolar transistor 28.

Accordingly, the source 40 of NFET 26 is equivalent to the

emitter 42 of the parasitic bipolar transistor 28. The body 34 of NFET 26 becomes charged by induced leakage whenever the drain 36 and source 40 terminals are held at a high potential. If the source 40 is dropped to a low potential 5 the trapped charged in the body 34 causes a current to flow from the base 32 of the parasitic bipolar transistor 28. This causes a current to flow in the collector 38 that is parallel to a current flowing in the drain 36. This action discharges the drain 36 node of a dynamic circuit.

10 Figure 3 is a schematic diagram of a dynamic logic circuit 44 illustrating one embodiment of the present invention. The dynamic logic circuit 44, as illustrated, eliminates the unwanted effects of the parasitic bipolar transistor 28 in SOI FET dynamic circuits. The dynamic 15 circuit includes a clock 88, several inputs, 50, 52, 54, and 56, and an output 80.

The clock input is tied to positive field effect transistor (PFET) 78 through its gate input terminal 46. When the input clock signal 88 is active low, PFET 78 turns 20 on and charges drain node 48 to a high potential. This is referred to as the pre-charge phase in dynamic logic circuits. During the pre-charge phase inputs 50, 52, 54, and 56 are set to a logic low state. While input 50 is in a logic low state, PFET 58 turns on and conducts current from 25 node 62 through drain terminal 82 and through source terminal 84, which is connected to the dynamic circuit's

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common or ground potential. Similarly, when input 54 is in a logic low state, PFET 60 turns on and conducts current from node 64 through to circuit common or ground. During the pre-charge phase PFETs 58 and 60 actively discharge intermediate nodes 62 and 64 of defined by stacked transistors 70 and 72. Accordingly, bodies 66 and 68 of NFETs 70 and 74, respectively, cannot charge to a high potential. Therefore, the parasitic bipolar transistors in parallel with NFETs 70 and 72 cannot activate because there is insufficient charge built up in bodies 66 and 68 to generate an adequate amount of base current into the parasitic bipolar transistors. By preventing the parasitic bipolar transistors from activating the charge on the drain node 48 of NFETs 70 and 74 is protected from being unintentionally discharged. Those skilled in the art will appreciate that if inputs 50 and 54 are complementary they may originate from logic circuits other than dynamic logic circuits. Accordingly, these inputs may originate from a latched circuit, for example.

20 The gate terminals 86 and 90 of active discharge devices PFETs 58 and 60, respectively, are connected to inputs 50 and 54 of stacked NFETs 70 and 74, respectively.

As well as providing for the elimination of bipolar parasitic leakage current, PFET pre-discharging intermediate nodes 62 and 64 also improves the noise immunity of dynamic logic circuit 44 by increasing the threshold voltage, V_t , of

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NFET transistors 70 and 74. The V_t of NFETs 70 and 74 is higher when PFET pre-discharging transistors 58 and 60, respectively, are present in dynamic logic circuit 44. The higher V_t increases the noise rejection of transistors 70 and 74. In other words, a higher magnitude of electrical noise voltage occurring at gates 50 and 54 of NFET transistors 70 and 74, respectively, is required to cause false switching in dynamic logic circuit 44.

In MOS FET transistors V_t is the threshold voltage at which point the transistor begins conducting current between the drain terminal and the source terminal, i.e. turns on. Accordingly, increasing the V_t increases the threshold at which the MOS FET transistor turns on. Therefore, a greater magnitude of spurious electrical noise voltage at the gate terminals is required to turn the MOS FET transistor on, thus causing a false switching of the dynamic logic circuit.

Given the symmetry of the FET devices, one skilled in the art would appreciate that similar results would be obtained if PFET transistors were replaced with NFET transistors and interconnected to perform the function of pre-charging the intermediate nodes of a dynamic logic circuit. Figure 4 illustrates one embodiment of the present invention utilizing NFET transistors 96 and 98 to pre-charge intermediate nodes 92 and 94, respectively, of dynamic logic circuit 100.

Greater noise immunity in dynamic logic circuit 100 is

achieved by utilizing NFET transistors 96 and 98 to pre-charge intermediate nodes 92 and 94, respectively. The NFET pre-charging transistors 96 and 98 increase the absolute value of the threshold voltage, V_t , of PFET transistors 102 and 104, respectively, thus improving the noise rejection capability of dynamic logic circuit 100.

The present invention has been described in its presently contemplated best mode, and it is clear that it is susceptible to various modifications, modes of operation and 10 embodiments, all within the ability and skill of those skilled in the art and without the exercise of further inventive activity. Further, while the invention has been described in connection with what is presently considered the most practical and preferred embodiments, it is to be 15 understood that the invention is not limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

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